STUDY OF HOT WIRE ANEMOMOMETRY AND FLOW MEASUREMENT ELEMENTS

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of

Bachelor of Technology
in
Electronics and Instrumentation Engineering

By

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Department of Electronics & Communication Engineering
National Institute of Technology, Rourkela
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DECLARATION

We hereby declare that the project work entitled "**Study of Hot wire anemometry and flow measurement elements**" is a record of our original work done under Prof. Tarun Kumar Dan, National Institute of Technology, Rourkela. Throughout this documentation wherever we get help from others, every endeavor has been made to acknowledge this clearly with due reference to literature. This work is being submitted in the partial fulfillment of the necessities for the degree of Bachelor of Technology in Electronics and Instrumentation Engineering at **National Institute of Technology, Rourkela** for the academic session 2011 – 2015.

The results embodied in the thesis are our own and not copied from other sources, wherever materials from other sources are put, due reference and recognition is given to original publication.

DEEPIKA PATRA (111EI0253) SURAJ KU. KESHRI (111EI0512)

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CERTIFICATE

This is to certify that the thesis entitled "**STUDY OF HOT WIRE ANEMOMETRY AND FLOW MEASUREMENT ELEMENTS**", submitted by Ms. DEEPIKA PATRA (111EI0253) and SURAJ KUMAR KESHRI(111EI0512) for the award of Bachelor of Technology Degree in 'ELECTRONICS & INSTRUMENTATION' Engineering at the National Institute of Technology (NIT), Rourkela is an authentic work carried out by them under my supervision.

Date: 7^{th} May,2015

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It would be our immense pleasure to take this as a chance to represent our appreciation and earnest because of our regarded Prof. Tarun Kumar Dan for the direction, knowledge, and bolster that he has given all through this work. Our present work would never have been conceivable without his basic inputs and tutoring.

We also want to thank every one of our friends, faculty team and all staff of our prestigious Department of Electronics and Communication Engineering, N.I.T Rourkela for their amazing help all through our course of learn at this organization.

DEEPIKA PATRA (111EI0253)　　　　SURAJ KU.KESHRI (111EI0512)

ABSTRACT

In industries,flow of any fluid varies over a very wide range.It ranges from very low to very high velocity. Because of this variation, various types of flow measurement elements have been developed. Out of all these, hot wire anemometry, orifice meter and rotameter are widely used. Responses of fluids with different densities and sensors with different diameters have been studied. Since these components are delicate to heat exchange between the component and its composition, temperature and environment, their responses vary with conditions provided.

Using hot-element sensor we also measured the concentration of gas components in a mixture of two known gases. This method is based on thermal conductivity of mixture. Thermal conductivity of mixture depends on individual thermal conductivities of gases of mixture and individual fractional concentration of that gases. Taking different types of probes and different types of fluid we compare the behavior of sensor so that we can determine the best conditions for measurements of properties like velocity and composition of fluids.

We also design and analyze the fuel metering valve. Fuel metering valve show nonlinear behavior and traditional methods are only optimize and analyzed the systems which is linear control system. Using flow gain (G) the fuel metering valve's flow rate is linearized. The relation between flow orifice's shape, along with rectangular, circular and triangular shape and its gain of steady state flow is discussed at the end.

Flow measurement is also done using rotameter.It is a constant pressure and variable area type flowmeter.Though with accuracy around 2%,it has gained a lot of importance in today's industries.We have also designed diameter for orifice plate considering different properties of fluid flowing through it like density, specific heat ratio,dynamic viscosity etc.Thus,a thorough study of flowmeters has been done.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

HOT WIRE

ANEMOMETER

1.1 DEFINATION AND BREIF REVIEW

Anemometry based on thermal properties is extensively used as a tool in research. From past many years, it has gained its importance in industries also. Here in hot wire anemometer, we will use a tiny electrically heated element placed in a flowing fluid for measuring the velocity and other properties like turbulence, flow pattern, level of that fluid. The principle of hot-wire anemometer is based on heat transfer by convection method from a heated element exposed to the fluid flow and if there is any change in the fluid medium it will cause a change in heat loss in sensor .It is an ideal tool for measuring velocity fluctuation in time domain in turbulent flows.

There are two types of probe-(1) hot wire and (2) hot film.

1.2 HOT WIRE SENSORS

Figure.1.1 shows probe of hot wire anemometer made up of tungsten. Generally diameter of probes ranges from 0.0038 to 0.005 mm and length from 1.0 to2.0 mm. The most commonly used materials for wire are tungsten, platinum and alloy of platinum-iridium. Although wires made up of tungsten are considered to be tough and high temperature coefficient of resistance is their property, (0.004/^{O}C) in many cases high temperature becomes unfavourable for their use because of low oxidation resistance. In the case of platinum, its main properties are good oxidation resistance as well as very good temperature coefficient (0.003/^{O}C), but it becomes weak specially at greater temperatures. Platinum-iridium wire is a bargain between platinum and tunsten having quality resistance for oxidation, and higher durability than platinum, but low resistive coefficient of temperature (0.00085/^{O}C) is its property. Now-a-days tungsten is more popular as compared to other hot wire material. To raise bond with the plated closures and the support needles a thin platinum coating is usually applied.

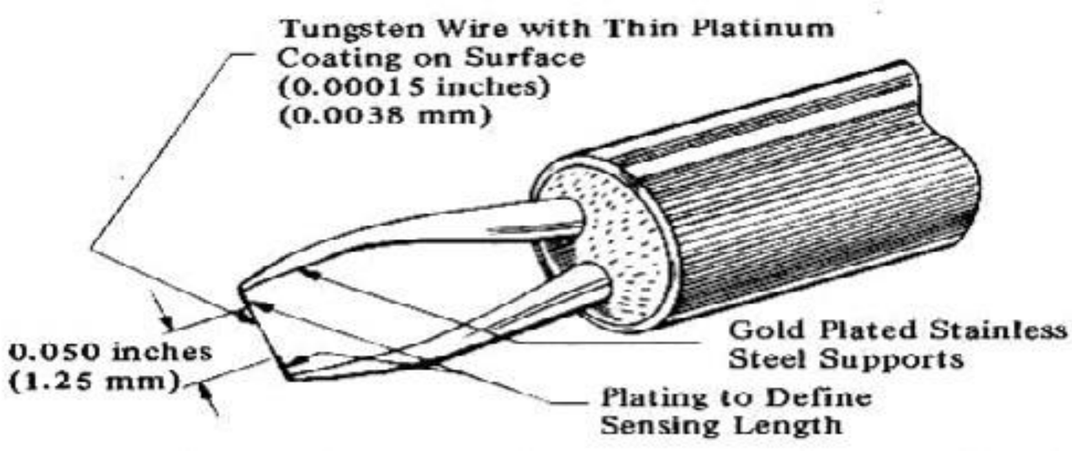
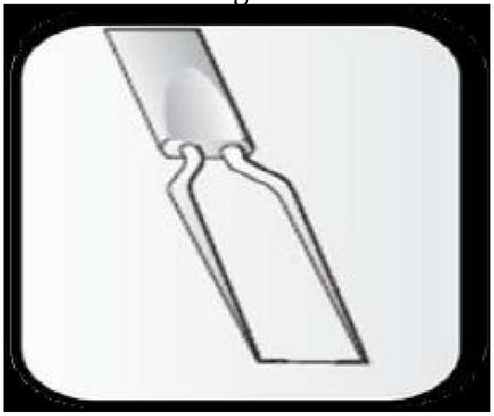


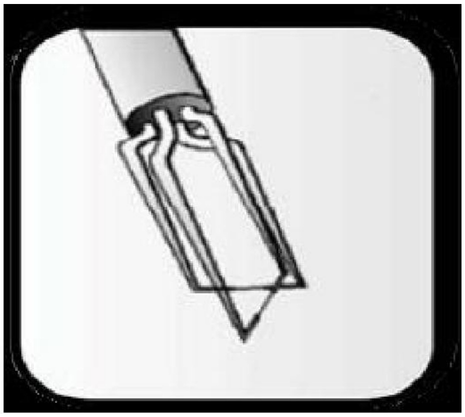
Figure 1.1: Tungsten Hot Wire Sensor and Support Needles

1.2.1 CLASSIFICATION OF HOT WIRE PROBES

On the basis of number of sensors used hot wires probes are classified into one-, two- and three-dimensional versions as single-, dual and triple sensor probes. Probes which have two or more sensors give information about magnitude as well as direction of velocity of fluid flow when placed under different angles to the flow vector.



(a)



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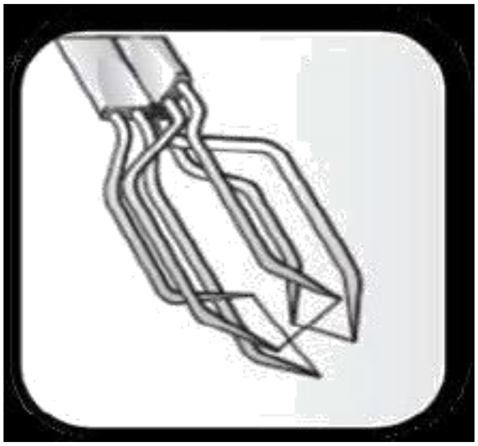


(c)

Figure 1.2: (a) Single Sensor Probe, (b) Dual Sensor Probe, (c) Triple Sensor Probe

The hot wire anemometer can be operated in either of the modes (1) constant temperature or (2) constant current. Mostly we have concentrated here on constant temperature mode.

1.3. HEAT TRANSFER EFFECTS IN MEASUREMENT SYSTEM

The sensing element's temperature at any time relies on the rate of heat exchange both to the sensor and vice versa. Heat transfer happens as an after effect of three possible methods of mechanism- **radiation, Convection and conduction.** This chapter of our thesis is mechanism for heat transfer is convection.

From Newton's law of cooling, the flow of heat involved in convection is W watts. This is between a sensing element which is at T°C and fluid in which sensor is placed at T_f °C is presented by:

$$\mathbf{W = U\,A\,(T - T_f)}$$

Here, U $Wm^{-2}\,°C^{-1}$ is the heat transfer coefficient for convection process and the heat transfer area is given by A in m^2 . Heat transfer coefficients are found out using the correlation formula:

$$\mathbf{Nu = \Phi(Re, Pr)}$$

between the three dimensionless numbers:

Nusselt Number $\quad n_u = \frac{Ud}{k}$

Reynolds Number $\quad R_e = \frac{vd\rho}{\eta}$

Prandtl Number $\quad P_r = \frac{c\eta}{k}$

The function Φ is found out tentatively; its structure relies on the shape and size of sensor, the convection type taking place and in which direction fluid is flowing with respect to the sensing element. Lets take an example- the correlation form for forced convection cross-flow in a cylindrical tube is

$$Nu = 0.48 (Re)^{0.5} (Pr)^{0.3}$$

1.4 FLUID FLOW SENSOR WITH SELF HEATING CURRENT

When a current of magnitude I is passed over a resistive component for example-a semiconductor film or fine metal wire, then the component is heated to a temperature T which is more than fluid temperature, T_f . The resistance of resistive component R_T at temperature T depends on the harmony between electrical power i^2R_T and the rate of aggregate convective warmth exchange in the middle of component and liquid, the component is utilized as a fluid velocity sensor. The heat offset mathematical statement is:

$$i^2 R_T - U(v)A(T - T_F) = MC\frac{dT}{dt} \tag{1}$$

Where, $U(v)$ is the convective heat exchange coefficient in the middle of sensor and liquid. If $i_o,\ R_{T_o},\ T_o,\ and\ v_o$ speak to consistent harmony conditions then:

$$i_o^2 R_T - U(v_o)A(T_o - T_F) = 0 \tag{2}$$

i , ΔR_T, Δv , ΔT are the little change from the above balance values, written as:

$$i = i_o + \Delta i , \qquad T = T_o + \Delta T$$

$$R_T = R_{To} + \Delta R_T \qquad U(v) = U(v_o) + \sigma\, \Delta v \tag{3}$$

In equation (3), $U(v_o) = (\partial U/\partial v)_{vo}$ i.e the rate of progress of U w.r.t v, calculated at equilibrium v_o. From (1) and (2) we have:

$$(i_0^2 + \Delta i)^2 (R_{T0} + \Delta R_T) - (U(v_0) - \sigma\Delta \upsilon)A(T_0 + \Delta T - T_F)\Delta v = MC(d\Delta T/dt)\ (T_0+\Delta T) \tag{4}$$

Dismissing all the terms including the duplication of little amounts gives:

$(i_0^2 + 2\, i_0 \Delta i) R_{T0} + i_0^2 \Delta R_T - U(v_0) A (T_0 - T_F) - U(v_0) A \Delta T - A(T_0-$

$T_F)\Delta v = MC(d\Delta T/dt)$ (5)

Subtracting (2) from (5) gives:

$2 i_0 R_{T0} \Delta I + i_0^2 \Delta R_T - U(v_0)\, A\Delta T-$

$\sigma A(T_0 - T_f)\Delta v = MC d\Delta T/dt$ (6)

ΔT can be removed by putting $K_T = \Delta R_T / \Delta T$ ie $\Delta T = (1/K_T)\, \Delta R_T$ where K_T is the slope of the resistive component temperature characteristics is:

$[(U(v_0)\, A/K_T) - i_0^2]\, \Delta R_T + (MC/K_T)\, (d\Delta R_T/dt) = 2 i_0 R_{T0} \Delta I - \sigma A(T_0 - T_f)\Delta v$ (7)

i.e.

$\Delta R_T + \tau_v\, (d\Delta R_T/dt) = K_I \Delta i - K_v \Delta v$ *(8)*

Where

$\tau_v = MC/\, (U(v_0) A - i_0^2 K_T)$ (9)

$K_I = (2 K_T R_{T0}\, i_0)/\, (U(v_0) A - i_0^2 K_T)$

$K_v = K_T \sigma A(T_0 - Tf)/\, (U(v_0) A - i_0^2 K_T)$

Taking the laplace Transform of [eq 8] gives:

$(1 + \tau_v s) \Delta R_T' = K_I \Delta I' - K_v \Delta v'$

i.e.

Transfer function for fluid velocity sensor

$$\Delta \bar{R}_T = \left(\frac{K_I}{1+\tau_v s}\right)\Delta i - \left(\frac{K_v}{1+\tau_v s}\right)\Delta \bar{v}$$

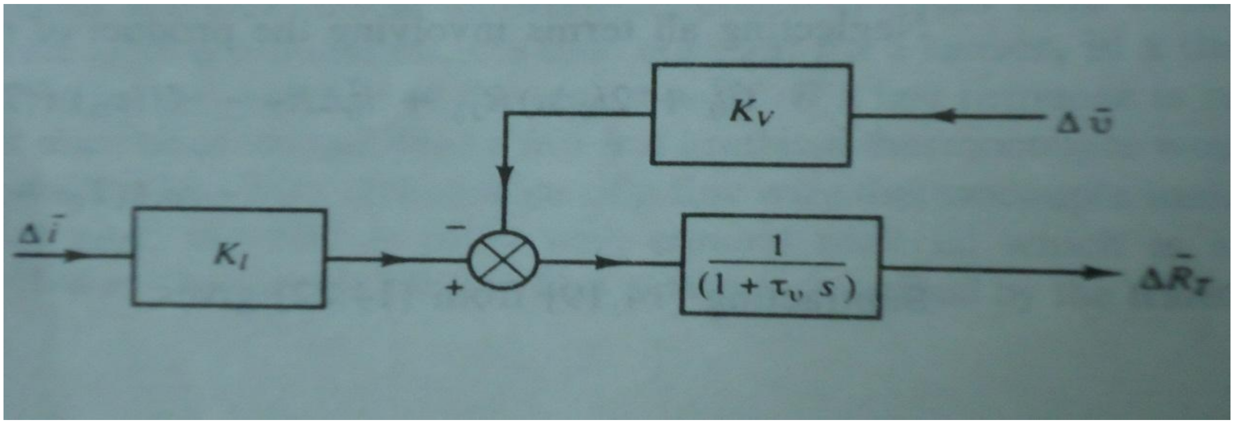


Figure 1.3: Block Diagram of thermal velocity sensor

1.5 CONSTANT TEMPERATURE ANEMOMETER SYSTEM FOR FLUID VELOCITY MEASUREMENTS

1.5.1 Steady-State characteristics

From the above results the steady-state equilibrium equation for a fluid velocity sensor with self-heating current is:

$$I_0{}^2 R_{T0} = U(v)A(T_0 - T_f) \tag{11}$$

In a CTA system the temperature T_0 and resistance R_{T0} of the sensing element are managed at constant values. From (11) we seen that if the fluid velocity v increases , which causes U(v) to increase, then the system has to rise the current i over the sensing element in order to re-establish equilibrium. After all resistance of sensor R_{TO} maintain fixed, the voltage drop iR_{TO} across the component increase because of the increase in current , thus providing a voltage signal which depends on fluid velocity sensors. That is:

$$Nu = 0.24+0.56Re^{0.5} \tag{12}$$

$$\text{Giving } U = 0.24k/d + 0.56k(pv/dn)^{0.5} \tag{13}$$

$$U=a+b\sqrt{v} \tag{14}$$

Where

$a=0.24k/d$

$b=0.56k(p/dn)^{0.5}$

We can see that since a and b depends upon dimension of sensing element d and the properties of fluid k, p, n, for a given fluid having a given sensor, they are constant.

Figure 1.4 is a schematic diagram of a constant-temperature anemometer system. Here a self – balancing bridge is used which maintains the resistance R_T of the sensor at a constant value R. When fluid velocity increases, temperature and resistance decreases and as a result of that, bridge becomes unbalanced. To balance all these output current of amplifier and current through the sensing element increase, restoring R_T and T to up to desired values. After all $R_T = R$ and $R_T = R_0(1 + \alpha T)$ for a metallic sensing element , then the fixed temperature T of the sensing element is:

$$T=(1/\alpha)(R/R_0-1) \tag{16}$$

From (2) , (14) and (16) we have:

$$I^2R = A(a+b\sqrt{v})((1/\alpha)(R/R_0-1)-T_f) \tag{17}$$

So $E_{out} = iR$

$$E^2_{out}=AR(a+b\sqrt{v})((1/\alpha)((R/R_0)-1)-T_f) \tag{18}$$

$$E_{out}=(E_0^2+y\sqrt{v})^{0.5} \tag{19}$$

Where

$$E_0^2=ARa((1/\alpha)((R/R_0)-1)-T_f) \text{ and } y=ARb((1/\alpha)((R/R_0)-1)-T_f) \tag{20}$$

1.5.2 DYNAMIC CHARACTERISTICS

We now ascertain the exchange capacity of the fixed temperature anemometer framework to check whether the recurrence reaction is adequate to identify quick speed vacillations because of turbulence and vortex shedding. The system equations are:

Sensor $\Delta R_T=(K_I\Delta I-K_v\Delta v)/\ (1+\tau_v s)$ (21)

Bridge $\Delta V=K_B\Delta R_R$ (22)

Amplifier $\Delta i=K_A\Delta v$ (23)

Output voltage $\Delta E_{out}=R\Delta i$ (24)

Resultant change in bridge resistance $\Delta R_R=\Delta R-\Delta R_T=-\Delta R_T(\Delta R=0)$ (25)

From (22-25)

$\Delta R_T=(-1/RK_AK_B)\Delta E_{out}$ and $\Delta i=\Delta E_{out}\ /R$ (26)

Substituting (25) in (21) gives:

$(-1/RK_AK_B)\Delta E_{out}\ =(1/1+\tau_v s)((K_l/R)\ \Delta E_{out}\ -K_v\Delta v)$

Rearranging we have:

$[(1+K_l\ K_A\ K_B)+\ \tau_v s]\ \Delta E_{out}\ =K_v\ K_A\ K_B\ R\Delta v$

Giving

$(\Delta E_{out}\ /\Delta v)s=K_{CTA}/(1+\tau_{CTA}S)$ (27)

Where

$K_{CTA}=K_v\ K_A\ K_B\ R/1+K_l\ K_A\ K_B$ and $\tau_{CTA}=\tau_0/1+K_l\ K_A\ K_B$

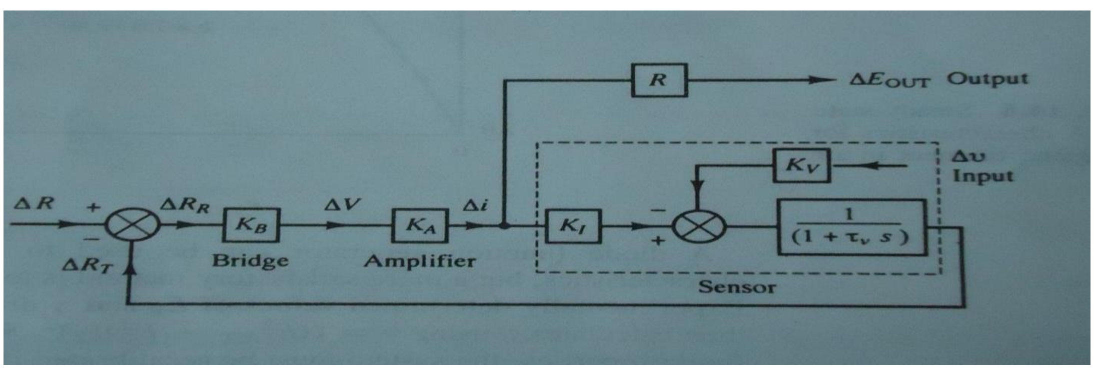


Figure 1.4: Block diagram of constant temperature anemometer

CHAPTER 2

ANEMOMETER SYSTEM FOR MEASUREMENT OF COMPOSITION OF GASES IN MIXTURE

2.1 INTRODUCTION:

The concentration of gas components in a mixture of two known gases can also be measured by a hot-element sensor. Thermal conductivities ϑ of gases vary. For dry air, ϑ=2.38*10^{-3} J/(m.s.K)

Thermal Conductivity for mixture of two gases is:

$$\vartheta = g_1\vartheta_1 + g_2\vartheta_2$$

Where, ϑ_1 & $\vartheta_2 = Thermal\ Conductivities\ of\ gases\ 1\ \&\ 2,\ respectively,\ J/(m.s.K)$

g_1 & $g_2 = gas\ concentration\ as\ fractional\ of\ unity\ for\ gases\ 1\ \&\ 2, respectively.$

Since $g_1 = 1 - g_2$, measuring ϑ is sufficient for detecting g_1 & g_2; therefore, the concentration are

$$g_1 = \frac{\vartheta - v_2}{v_1 - v_2} \quad \& \quad g_2 = \frac{v_1 - \vartheta}{v_1 - v_2}$$

If the gas to be tested is forced to flow with a stable speed through a cell having a thin, heated wire in a pipe, cooling of the wire (depending on the gas concentration) changes the wire resistance. This resistance is a measure of the concentration.

It should be noted that above formula gives an approximation relationship for the gas mixture. More exact evaluation of the gas content can be done by calibration of the instrument using gas samples.

Taking the construction shown in figure as a model, we can derive a transfer characteristics for the element. Fourier's law of heat conduction states that the rate of heat flow through a substance is proportional to the area normal to the direction of the flow and to the negative of the temperature rate change with distance along the direction of the flow. It means that the heat loss from the elementary surface of the wire is

$$dQ = -\vartheta dA \frac{d\theta}{dr}$$

Where,

dQ = elementary heat flow rate from the surface, J/s

$dA = elementary\ surface,\ m^2$

$\frac{d\theta}{dr} = gradient\ of\ the\ temperature\ along\ radius\ r, \frac{K}{m}$

The temperature distribution along the radius is found by taking integral of above equation with respect to the radius:

$$\theta = \theta_P - \frac{1}{2\pi\vartheta}\frac{dQ}{dl} ln\frac{r_w}{r_P}$$

Where,

$\theta_P = temperature\ at\ pipe\ wall,\ K$

$r_w = radius\ of\ wire,\ m$

$r_P = radius\ of\ pipe,\ m$

$l = wire\ length,\ m$

By taking one more integral of above equation with respect to length l the heat loss rate from the entire wire is obtained:

$$Q = \frac{(\theta_P - \theta_w)2\pi l}{ln\frac{r_w}{r_P}}$$

Assuming that the wire has resistance R and is heated by current I, the equation of the power is $Q=I^2R$, and

$$R = \frac{1}{I^2}\frac{(\theta_P - \theta_w)2\pi l}{ln\frac{r_w}{r_p}}\vartheta$$

Resistance R is a function of temperature: $R = R_o[1 + \alpha(\theta_w - 273)]$

Where, $R_o = resistance\ of\ wire\ at$ 0℃, Ω

$$\alpha = resistance - temperature\ coefficient\ of\ wire\ material. \frac{1}{K}$$

In this transfer characteristics, r_w, r_p, l, R_o And α are constants. If I and $\theta_P$are stabilized during the measurement, R simply defines ϑor the concentration in question.

CHAPTER 3

DESIGN AND ANALYSIS OF ORIFICE GEOMETRY FOR A FUEL METERING VALVE

3.1 INTRODUCTION

The fuel measurement is very important in automobile control systems that is done by a simplified fuel metering valve. This fuel which need to measure is generally fulfilled by the metering orifice which opens and shuts the flow area based on a controller feedback. A regulator is used to maintain constant pressure drop across orifice area. The problem in measurement of fuel using fuel metering valve is that the fuel metering valve is not linear in his full range. The reason for nonlinearity is changing of operating condition inside valve. Reasons is involve: 1) Area of the valve orifice varied nonlinearly, 2) Change in pressure caused change of fuel velocity, and 3) the discharge coefficient is also depend on geometry of valve. Using regulator the pressure changes can be keep constant under some condition. Also nonlinearity due to change in discharge coefficient can negligible. So only due to nonlinearity in orifice area is responsible for nonlinearity of fuel metering valve.

In fact using flow gain, the linear analysis design parameters and result is done for hydraulic nonlinear system. As being what is indicated, the nonlinear analysis of physical design is completely different from linear analysis. We studied the steady state analysis of flow gain for different shapes and size of orifice geometry. The progress of the fuel metering valve is evaluated utilizing traditional linear analysis as already discussed. Using equation of motion, valve's steady state expression can be assessed by steady state flow gain which, depend on orifice shapes. In this paper, the shape of orifice, rectangle, circle, and triangle, are considered. Non-linear simulation of fuel metering valve shows that the flow orifice of circle and triangle shapes have a nice steady state characteristics.

Figure l contain a simple figure of a fuel metering valve. The fuel metering valve contains a control spool (physically or electrically controlled), a hydrostat spool (self-control), a valve housing.

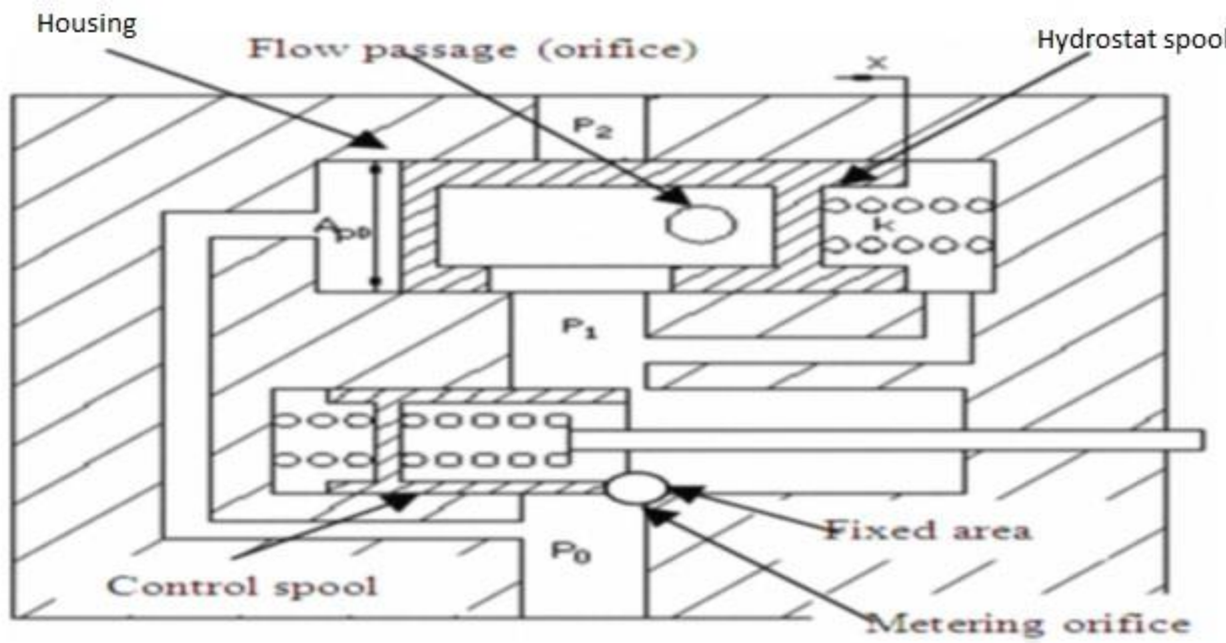


Figure 3.1: Fuel Metering Valve

3.2 MATHEMATICAL MODELLING

From figure-3.1 across the hydrostat spool the force balance expression is:

$$M\ddot{x} = F_0 - kx - B\dot{x} - A_{P_0}(P_0 - P_1) \quad (1)$$

Where M is mass of spool, B is damping constant of valve, F_0 is force on spool by spring when elongation is zero, A_{P_0} is valve area, k is spring coefficient, P_1 is outlet pressure of orifice and P_0 is inlet pressure of orifice.

Consider valve pressure described by rise-rate equation of standard pressure for control volume, using conservation of fuel mass and from fuel bulk modulus definition the state equation is:

$$\dot{P}_1 = \frac{\beta}{V}(Q_{in} - Q_{out} - \dot{V}) \quad (2)$$

Where, β is bulk modulus of fuel, V is is valve chamber volume, Q_{in} is inlet volumetric flow, and Q_{out} is outlet volumetric flow.

The instantaneous valve chamber volume is:

$$V = V_0 + A_{P_0}x \tag{3}$$

Where V_0 is volume of fuel in the valve when x equals to zero.

Equation of orifice using classical method is:

$$Q_{in} = C_d A_0 \sqrt{\frac{2(P_0 - P_1)}{\rho}} = C \tag{4}$$

Where A_0 orifice area of metering valve, C_d is discharge coefficient, ρ is density of fuel. Pressure changes across metering orifice is very small so Q_{in} take as a constant.

Now the equation of flow out through valve is

$$Q_{out} = C_d A(x) \sqrt{\frac{2(P_1 - P_2)}{\rho}} \tag{5}$$

Where $A(x)$ is flow area of orifice, P_1 is inlet pressure of hydrostat spool and P_2 is outlet pressure of hydrostat spool.

If we defined the instantaneous flow gain as:

$$G = C_d \sqrt{\frac{2(P_1 - P_2)}{\rho}} \left(\frac{A(x)}{x}\right) \tag{6}$$

Then outlet flow of valve chamber is written as:

$$Q_{out} = Gx \tag{7}$$

Assume that orifice area is linearly vary with x then the flow gain, G is constant.

Using equation (3), (4) and (7) in to equation (2) then equation become like that:

$$\dot{P}_1 = \frac{\beta}{V_0}(C - Gx - A_{P_0}\dot{x}) \tag{8}$$

Integrating above equation become:

$$P_1 = \frac{\beta}{V_0}\int(C - Gx)dt - \frac{\beta A_{P_0}}{V_0}x \tag{9}$$

Using equation (1) in equation (1) become the combination of differential and integral equation which written below as:

$$M\ddot{x} + B\dot{x} + \left(k + \frac{\beta {A_{P_0}}^2}{V_0}\right)x = F_0 - A_{P_0}P_0 + \frac{\beta A_{P_0}}{V_0}\int(C - Gx)dt \tag{10}$$

Again differentiate the equation (10) yields

$$M\dddot{x} + B\ddot{x} + \left(k + \frac{\beta {A_{P_0}}^2}{V_0}\right)\dot{x} + \frac{\beta A_{P_0}G_0}{V_0}x - \frac{\beta A_{P_0}}{V_0}C = 0 \tag{11}$$

3.3 STEADY STATE ANALYSIS

For steady state analysis of the fuel metering valve the time dependent components of the dynamic system are set to be zero. From equation (8) we can write the steady state expression for position of the valve as:

$$x_0 = \frac{C}{G_0} \tag{12}$$

Where, x_0 is valve position, G_0 is the gain of steady state flow and C is the flow rate of the valve. Based on equation (1) and (12), the steady state pressure inside the valve body can be derived as

$$P_{10} = \frac{1}{A_{P_0}}\left(\frac{kC}{G_0} + A_{P_0}P_0 - F_0\right) \tag{13}$$

From equation (13) it can be seen that the increment in flow rate C tends to increment the steady state pressure P_{10} of the valve. From equation (6), one can the gain of steady state flow is written as

$$G_0 = C_d\sqrt{\frac{2(P_{10} - P_2)}{\rho}}\left(\frac{A(x_0)}{x_0}\right) \tag{14}$$

From equation (12), (13) and (14) it is visualized that the flow gain G_0, the pressure P_{10}, and the position x_0, are not changed, only flow rate C, may be changed.

3.4 ORIFICE GEOMETRY

Figure 3.2 have the flow passage of rectangular, circular, and triangular shapes. In figure 3.2. the area shown as cross hatched is opening areas.

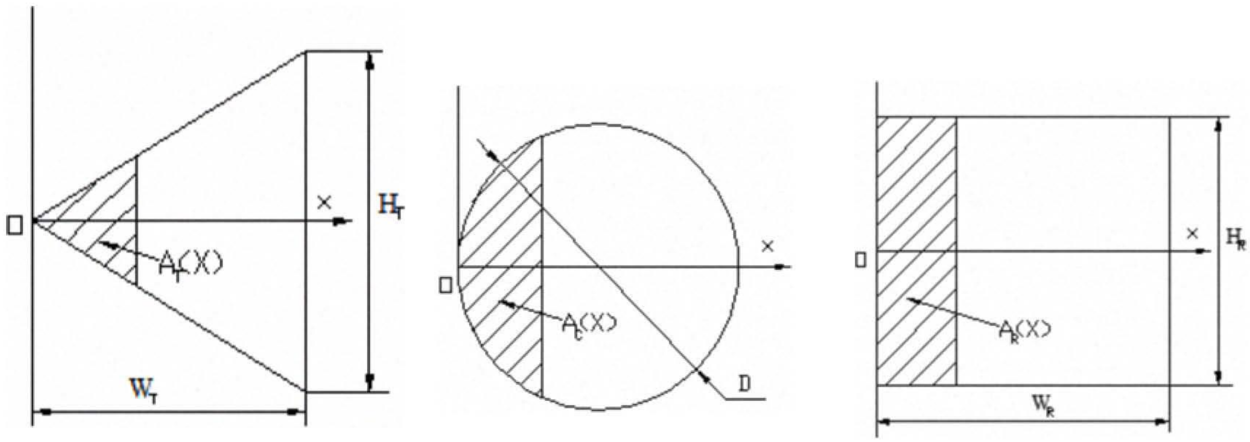


Figure 3.2: Shapes of orifice and opening areas

height H_r is

$$A_r(x) = H_r x \tag{15}$$

For flow passage of triangular shape of width W_t and height H_t is

$$A_t(x) = \frac{H_t}{2W_t} x^2 \tag{16}$$

And for flow passage of circular shape of diameter D is

$$A_c(x) = \frac{\pi D^2}{8} + \left(x - \frac{D}{2}\right)\sqrt{Dx - x^2} + \frac{D^2}{4}\sin^{-1}\left(\frac{2x-D}{D}\right) \tag{17}$$

CHAPTER 4

ROTAMETER AND CALCULATION OF ORIFICE METER DIAMETER, d

4.1 INTRODUCTION

Flow measurement is extremely important in all the process industries. The way in which the rate of flow is quantified depends on whether the quantity flowing is a solid, liquid or gas. In the case of liquid and gases, flow is usually measured in terms of the volume flow rate. Fluid are carried in pipes, and the volume flow rate is measured by different instrument like orifice plate, venture tube, flow nozzle, dall tube, pitot tube, rotameter, turbo meter, electromagnetic flow meter, ultrasonic flow meter. Here we used some flow meter to measure flow rate of fluid.

4.2 ROTAMETER

A rotameter is a gadget that measures the stream rate of fluid or gas in a shut tube. It has a place with a class of meters called variable zone meters, which measure stream rate by permitting the cross-sectional region the liquid goes through, to fluctuate, creating a quantifiable impact.

4.2.1 IMPLEMENTATION

A rotameter comprises of a decreased tube, commonly made of glass with a 'buoy', made both of anodized aluminum or an earthenware, really a molded weight, inside that is pushed up by the drag power of the stream and pulled around gravity. The drag power for a given liquid and buoy cross segment is an element of stream velocity squared just, see drag mathematical statement.

A higher volumetric stream rate through a given region builds stream speed and drag power, so the buoy will be pushed upwards. In any case, as within the rotameter is cone molded (extends), the territory around the buoy through which the medium streams expands, the stream speed and drag power diminish until there is mechanical balance with the skim's weight.

Floats are made in various shapes, with circles and ellipsoids being the most well-known. The buoy may be corner to corner scored and part of the way hued with the goal that it pivots pivotally as the liquid passes. This shows if the buoy is stuck since it will just turn in the event that it is free. Readings are typically taken at the highest point of the broadest piece of the buoy; the middle for an ellipsoid, or the top for a chamber. A few producers utilize an alternate standard.

The "float" must not skim in the liquid: it needs to have a higher thickness than the liquid, else it will buoy to the top regardless of the fact that there is no stream.

The mechanical way of the measuring rule gives a stream estimation gadget that does not require any electrical force. In the event that the tube is made of metal, the buoy position is exchanged to an outer pointer through an attractive coupling. This capacity has extensively extended the scope of uses for the variable zone stream meter, subsequent to the estimation can watched remotely from the procedure or utilized for programmed control.

4.2.2 ADVANTAGES

- A rotameter obliges no outer power or fuel, it utilizes just the intrinsic properties of the liquid, alongside gravity, to quantify stream rate.
- A rotameter is likewise a moderately basic gadget that can be mass fabricated out of modest materials, considering its across the board utilization.
- Since the range of the stream section increments as the buoy climbs the tube, the scale is pretty nearly straight.
- Clear glass is utilized which is exceptionally impervious to warm stun and chemical action.

4.2.3 DISADVANTAGES

- Due to its utilization of gravity, a rotameter should dependably be vertically arranged and right far up, with the liquid streaming upward.

- Due to its dependence on the capacity of the liquid or gas to uproot the buoy, graduations on a given rotameter might be precise for a given substance at a given temperature. The primary property of significance is the thickness of the liquid; then again, consistency might likewise be critical. Buoys are preferably intended to be harsh to consistency; nonetheless, this is at times evident from makers' determinations. Either separate rotameters for diverse densities and viscosities may be utilized, or various scales on the same rotameter can be utilized.

- Due to the immediate stream evidence the determination is generally poor contrasted with other estimation standards. Readout instability deteriorates close to the base of the scale. Motions of the buoy and parallax may further expand the instability of the estimation.

- Since the buoy must be perused through the streaming medium, a few liquids may cloud the perusing. A transducer may be needed for electronically measuring the position of the buoy.

- Rotameters are not effectively adjusted for perusing by machine; albeit attractive buoys that drive a supporter outside the tube are accessible.

• Rotameters are not by and large fabricated in sizes more noteworthy than 6 creeps/150 mm, however sidestep plans are here and there utilized on extensive pipes.

Figure 4.1: ROTAMETER IN LABORATORIES

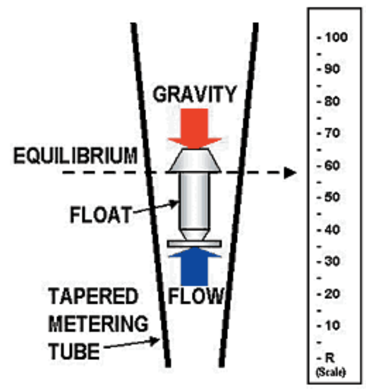


Figure 4.2: BASICS OF ROTAMETERS

4.3 CALCULATION OF ORIFICEMETER DIAMETER, d

4.3.1. Types of Differential Pressure Flowmeter

The four components that are utilized by and large are the orifice plate, Venturi, Dall tube and nozzle. Of these the hole i.e. orifice plate is the generally utilized. It is shoddy and accessible in an extensive variety of sizes. The fundamental drawbacks of orifice plate are the limited accuracy (±1.5% at best) and the high permanent pressure loss $(\Delta P)_P$. There are three plans of pressure tappings which are recommended to be used with orifice plates: corner, flange and $D - D/2$. The values of C are shown in Table 4.1 and are distinctive for every plan. Table 4.2 summarizes the fundamental parameters of the four elements. High measured differential pressure is combined by a Dall tube $(\Delta P)_M$ (like the orifice plate) with a low pressure loss which is permanent $(\Delta P)_P$ (better than Venturi).

Table 4.1 Discharge coefficient data for orifice plate

(a) The Stolz equation			
$C = 0.5959+0.0312ß^{2.1}-0.184ß^{8}+0.0029ß^{2.5}(10^{6}/Re)^{0.75}+0.0900L_1\,ß^{4}(1-ß^{4})^{-1}-0.0037L_2'\,ß^{3}$			
Note If L_1>=(0.0390/0.0900) (= 0.4333) use 0.0390 for the coefficient of $ß^{4}(1-ß^{4})^{-1}$			
(b) Values of L_1 and L_2'			
Corner tappings *D* and *D*/2 tappings Flange tappings			$L_1 = L_2' = 0$ $L_1 = 1$,* $L_2' = 0.47$ $L_1 = L_2' = 25.4/D$
(c) Conditions of validity			
	Corner taps	Flange taps	*D* and *D*/2 taps
d (mm)	$d \geq 12.5$	$d \geq 12.5$	$d \geq 12.5$
D (mm)	$50 \leq D \leq 1000$	$50 \leq D \leq 760$	$50 \leq D \leq 760$
ß	$0.23 \leq ß \leq 0.80$	$0.2 \leq ß \leq 0.75$	$0.2 \leq ß \leq 0.75$
Re	$5000 \leq Re \leq 10^{8}$ for 0.23 <= ß <= 0.45 10 000 <= *Re* <= 10^{8} for 0.45 < ß <= 0.77 20 000 $\leq$ *Re* $\leq 10^{8}$ for $0.77 \leq ß \leq 0.80$	$1260\,ß^{2}D† \leq Re \leq 10^{8}$	$1260\,ß^{2}D† \leq Re \leq 10^{8}$

Table:4.2

Parameter/meter	**venturi**	**nozzle**	**Dall tube**	**Orifice plate**
Approximate value of *C*	**0.99**	**0.96**	**0.66**	**0.60**
Relative values of measured differential pressure $(\Delta P)_M$	**1**	**1.06**	**2.25**	**2.72**
Permanent ΔP as % of $(\Delta P)_M$ i.e. $(\Delta P)_P / (\Delta P)_M$ *100%	**10-15%**	**40-60%**	**4-6%**	**60-70%**

To ascertain *d* we require exact estimations of *C*, *E* and ε. Since each of the three amounts are elements of *d* (via ß = *d*/*D*), an iterative count is needed. Figure 4.3 is a flow sheet for such one conceivable computation strategy; this is suitable for manual or computer usage.

Notes on flow sheet

1. Input data required are written as:

M_{MAX}	Maximum mass flow rate (kg s^{-1})
ΔP_{MAX}	Differential pressure at maximum flow (Pa)
P_1	Upstream pressure (Pa)
ρ_1	Density of fluid at upstream conditions (kg m−3)
η	Dynamic viscosity of fluid (Pa s)
γ	Specific heat ratio
δ	Machining tolerance (m)
D	Diameter of pipe (m)
i	Index of the fluid: *i* = 0 for liquid, *i* = 1 for gas
j	Tappings index: *j* = 0 for corner, *j* = 1 for flange, *j* = 2 for (*D* − *D*/2).

2. Calculation of Reynolds number uses M_{MAX} and pipe diameter D. Since $Re = \rho(vD/\eta)$ and since $v = M_{MAX} /(\rho\Pi D^2/4)$, $Re = 4 M_{MAX} /(\Pi D\eta)$.

3. The values of d, D, ß and Re must be checked against the states of legitimacy of the Stolz equation (Table 4.1). An introductory inexact checks that Re is greater than 10^4 is trailed by a last exact check once ß is established.

4. There is no reason for ascertaining d more precisely than the resistance δ to which the gap can be machined. This gives a basis to either proceeding with or closing the estimatioThus if d_{n-1}, d_n are respectively the (n - 1)th and nth guesses for d, then:

if $|dn - dn\text{-}1| > \delta$ continue calculation,

if $|dn - dn\text{-}1| <=\leq$ conclude calculation.

5. Since final values of C, ε and E will be near to the beginning theories, the figuring ought to oblige near to around six emphasess.

6. Since Venturi and Dall tubes are sold in standard sizes, an alternate methodology is needed. A rough computation will give the most suitable size; then an exact count of $(\Delta P)_{MAX}$ is carried out for the size chosen.

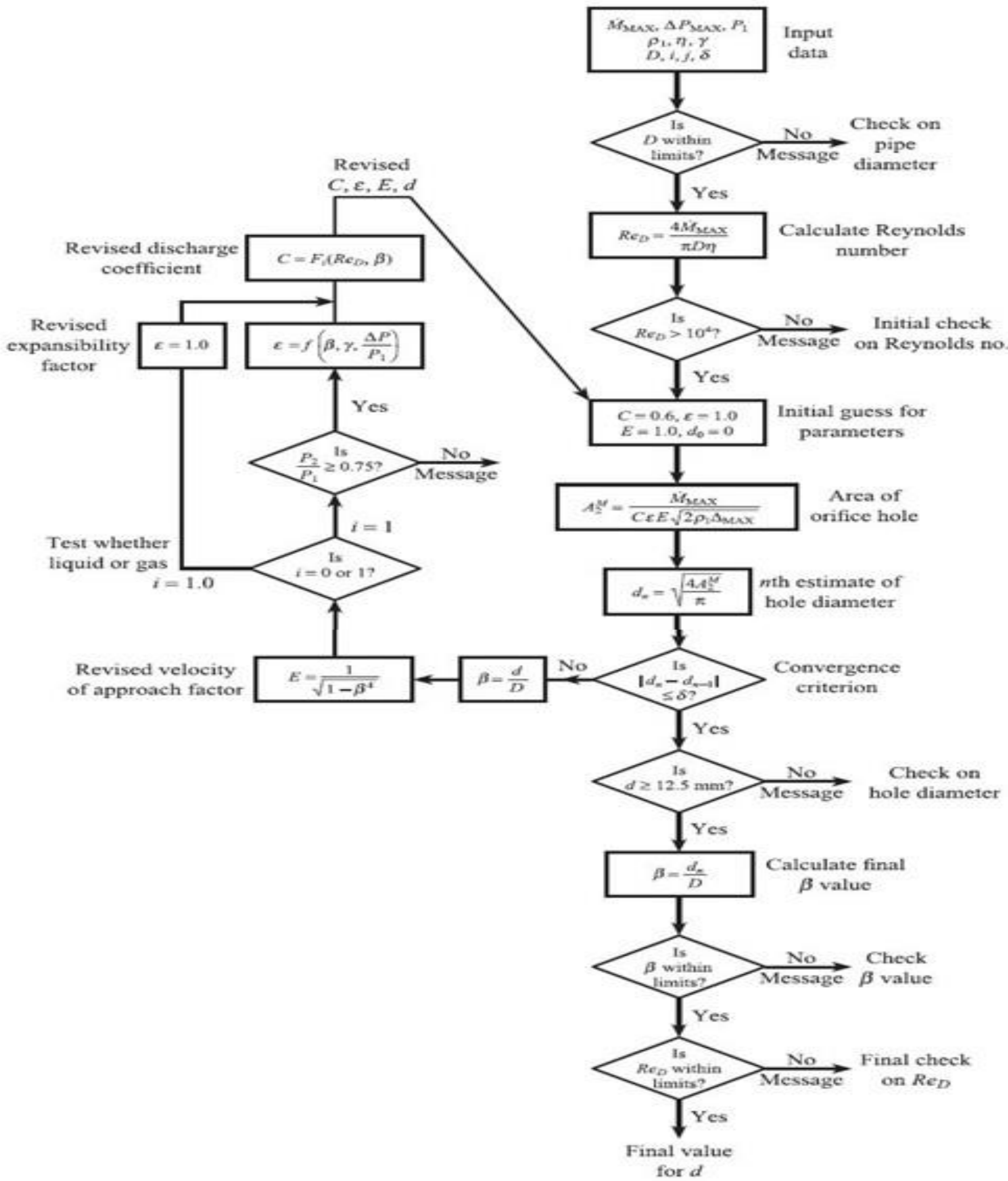


Figure 4.3: Flow chart for calculation of orifice meter diameter, d

CHAPTER 5

RESULTS

AND

OBSERVATIONS

5.1 RESULTS AND DISCUSSIONS ON HOT WIRE ANEMOMETER

After describing the whole process of hot wire anemometry, now we come up with the observation part. We have seen that a few factors affected the working of hot wire anemometry. Let us see how the fluid whose velocity is being measured affects the measurement.

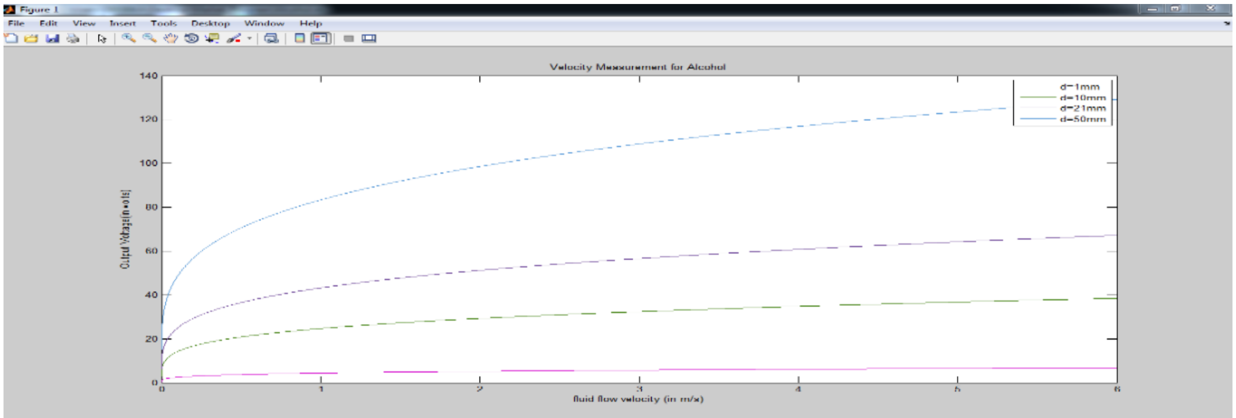
Here we will consider for **CONSTANT TEMPERATURE ANEMOMETER**

Given are values of few fluids which we will be using to check the dependence of the fluid on flow velocity.

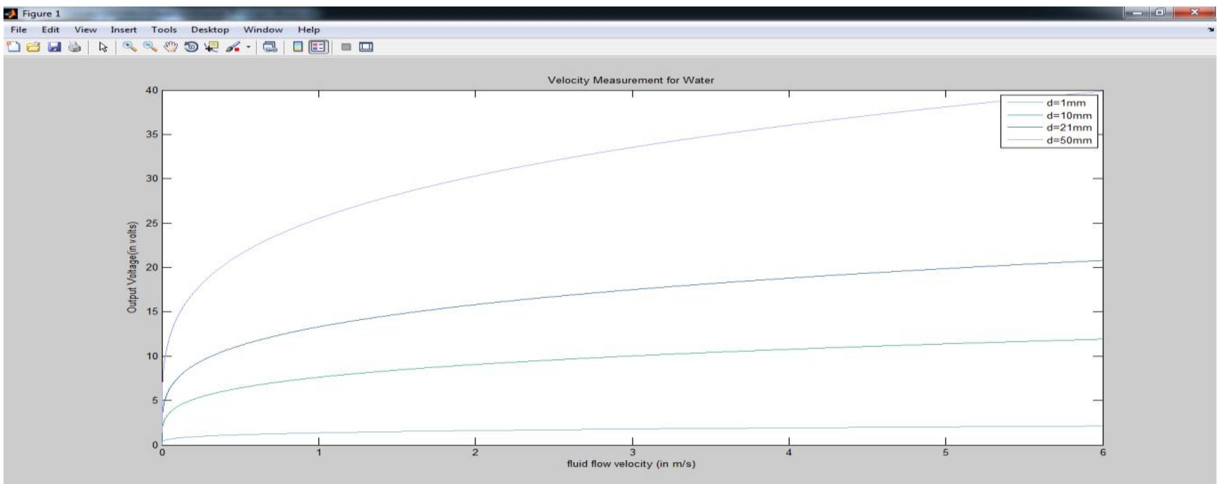
Table 1.0

Properties	alcohol	Water	Glycerine	Olive oil
k(fluid thermal conductivity) in W/m°C	0.17	0.016	0.28	0.17
ϸ (fluid density) in Kg/m^3	785	1000	1261	800
η (fluid viscosity) in Pas	0.001074	0.0013	1.2	0.081

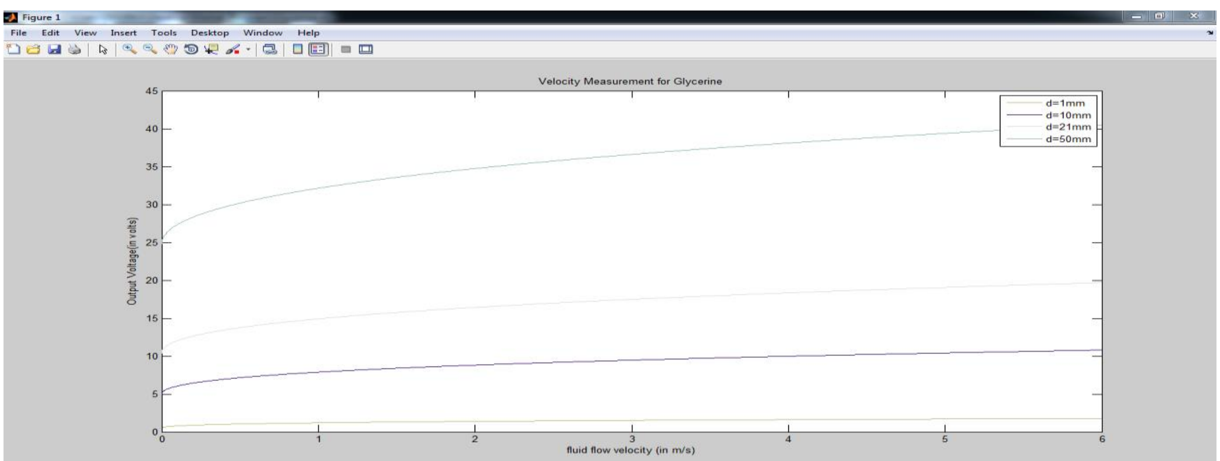
Calculating the values of a and b for different fluid we plot the graph for different sensors for alcohol by varying the diameter of sensor-



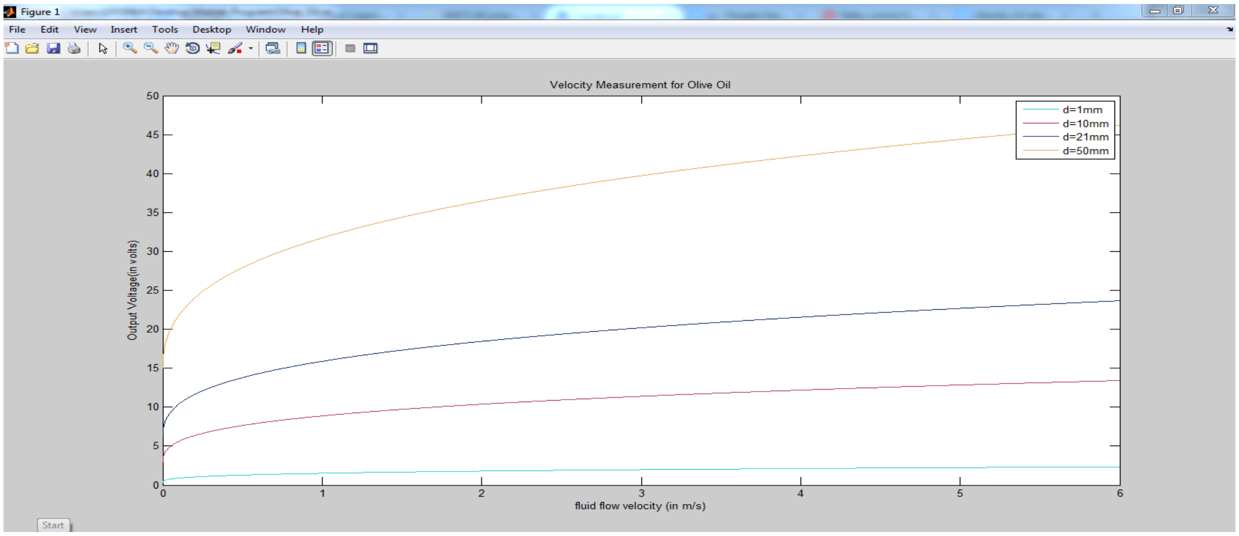
For water-



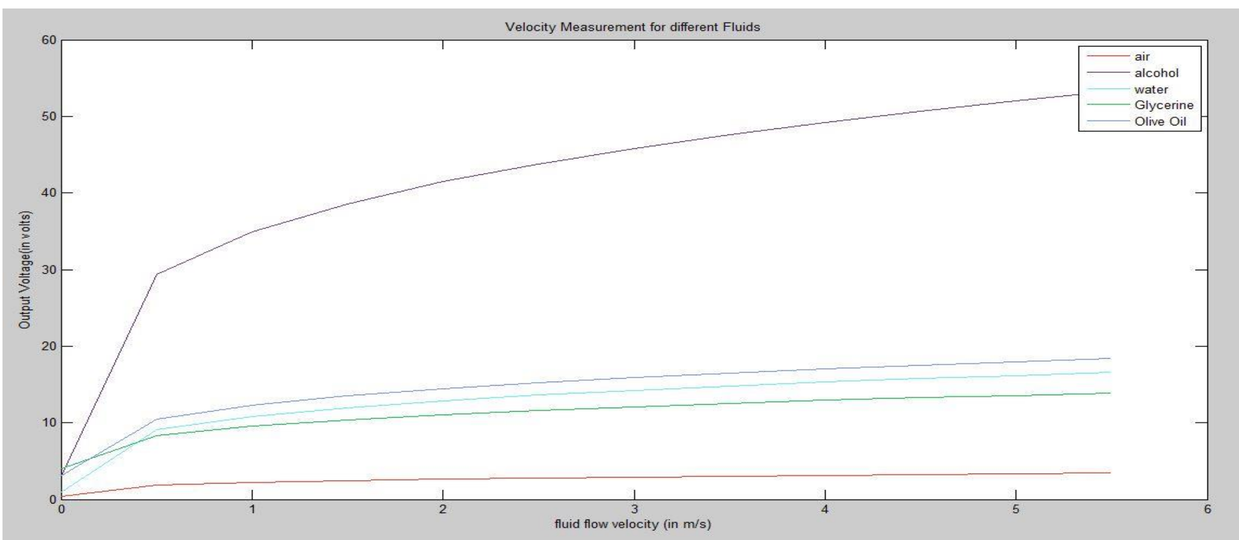
For glycerine-



For olive oil-



Considering fluids of different density:



5.2 COMPOSITION MEASUREMENT USING HOT WIRE ELEMENT

Taking data from book "Transducer and Their Element: Design and Application" for measuring composition of mixture of argon and oxygen gases.

$$\alpha = 4.29 \times 10^{-3} \frac{1}{K}, \quad I = 1\,A, \quad r_w = 4\,\mu m, \quad r_P = 4\,mm$$

$$l = 0.5\,mm, \quad \theta_P = 303\,K, \quad R_o = 66\,\Omega, \quad \theta_w = 313\ to\ 373\,K$$

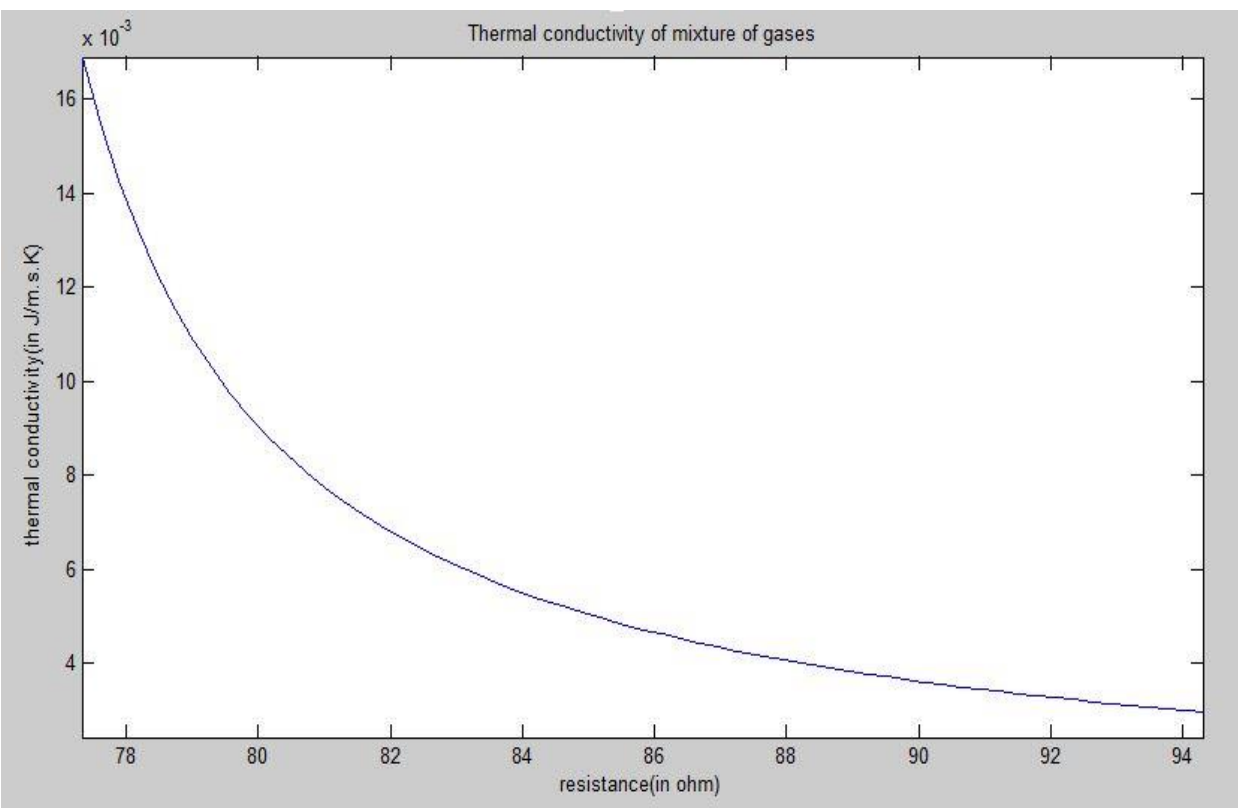
So after calculation,

$$R = 66[1 + \alpha(\theta_w - 273)]\,\Omega \qquad \text{and}$$

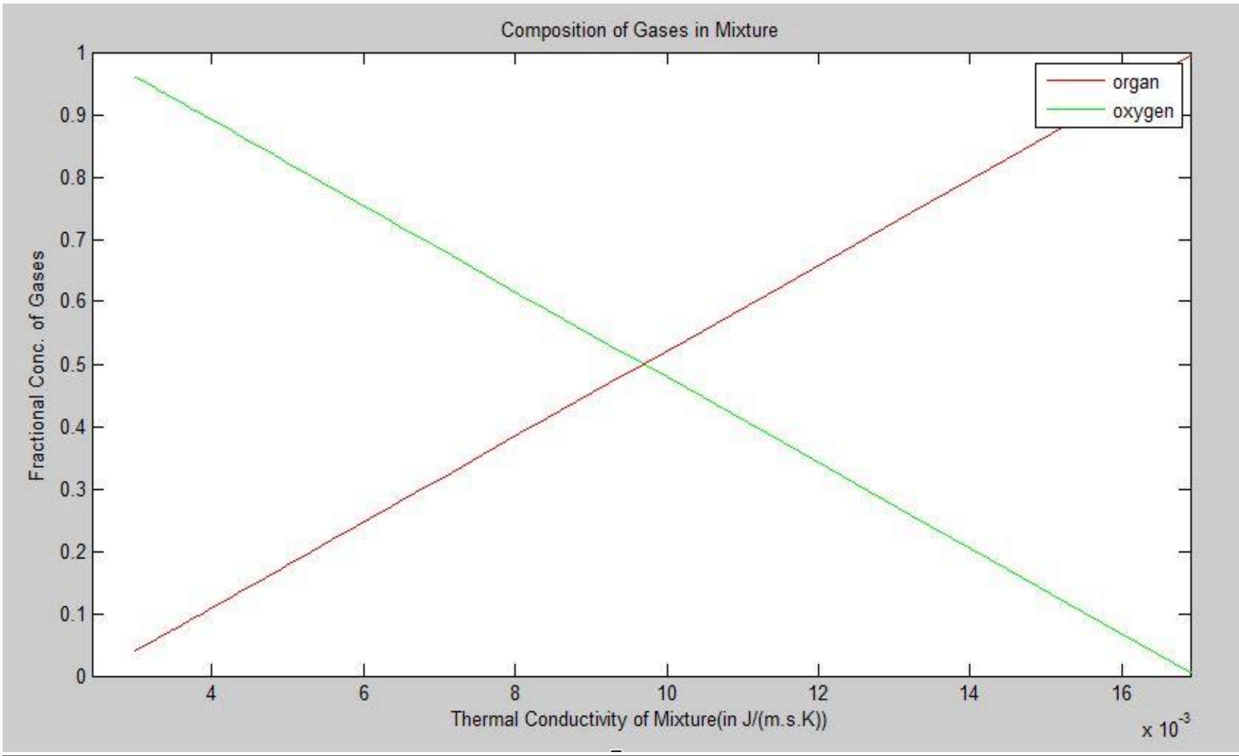
$$\vartheta = \frac{R}{(\theta_P - \theta_w)} \times \frac{-2.198}{1000}\ \mathrm{J/(m.s.K)}$$

$$g_{argon} = \frac{\vartheta - 2.42\times10^{-3}}{(16.9\times-2.42)\times10^{-3}} \quad \& \quad g_{oxygen} = \frac{16.9\times10^{-3} - \vartheta}{(16.9-2.42)\times10^{-3}}$$

Graph obtained for measuring thermal conductivity of mixture of gases:



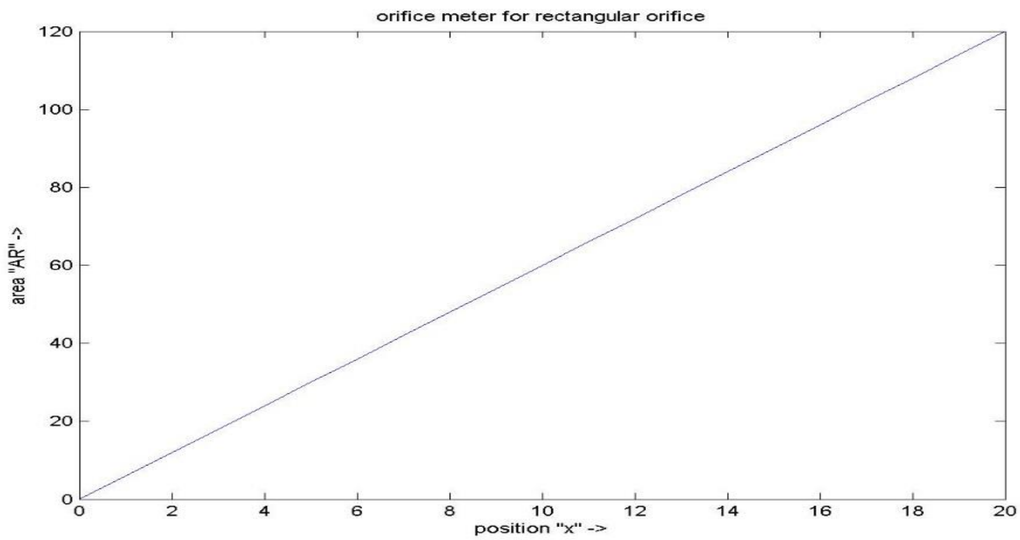
Graph obtained for composition of gases in mixture:



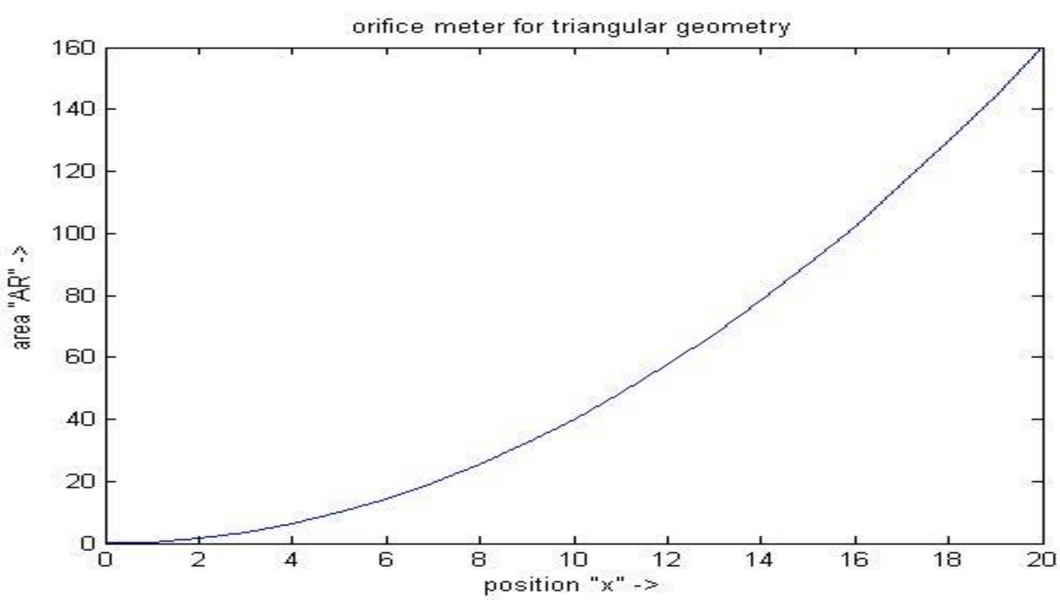
5.3 DESIGN AND ANALYSIS OF ORIFICE GEOMETRY FOR A FUEL METERING VALVE

In figure 3 the comparative area of different flow passages written in equation (15), (16) and (17) are shown in graph. Here the maximum areas and maximum width is equal for all flow passage. Variation in area for triangular and circular flow passage are nonlinear.

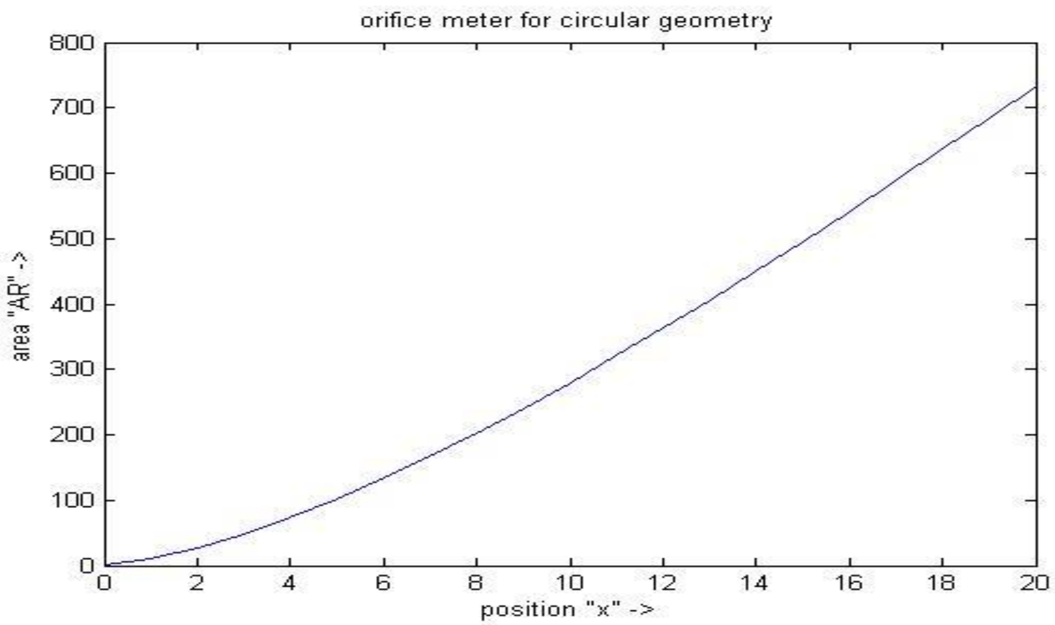
Graph between area and position for rectangular orifice:



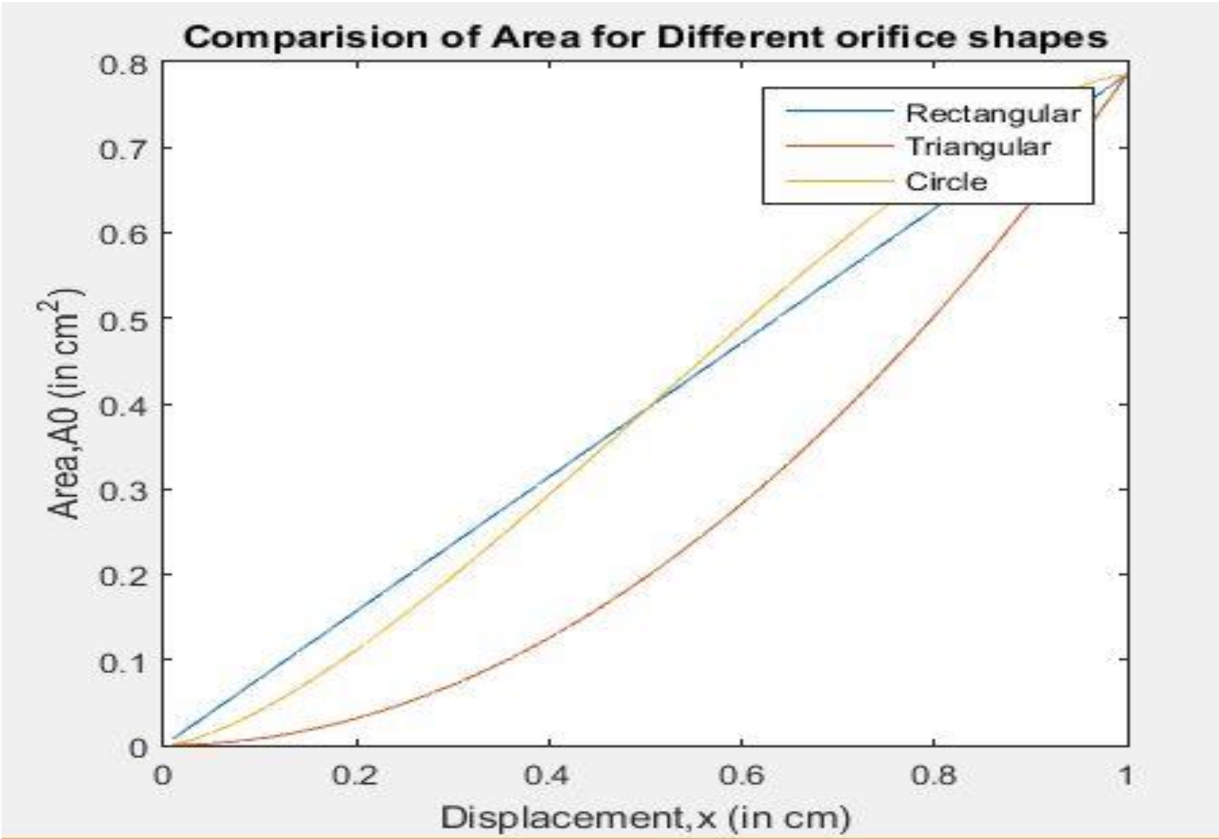
Graph between area and position for triangular orifice:



Graph between area and position for circular orifice:

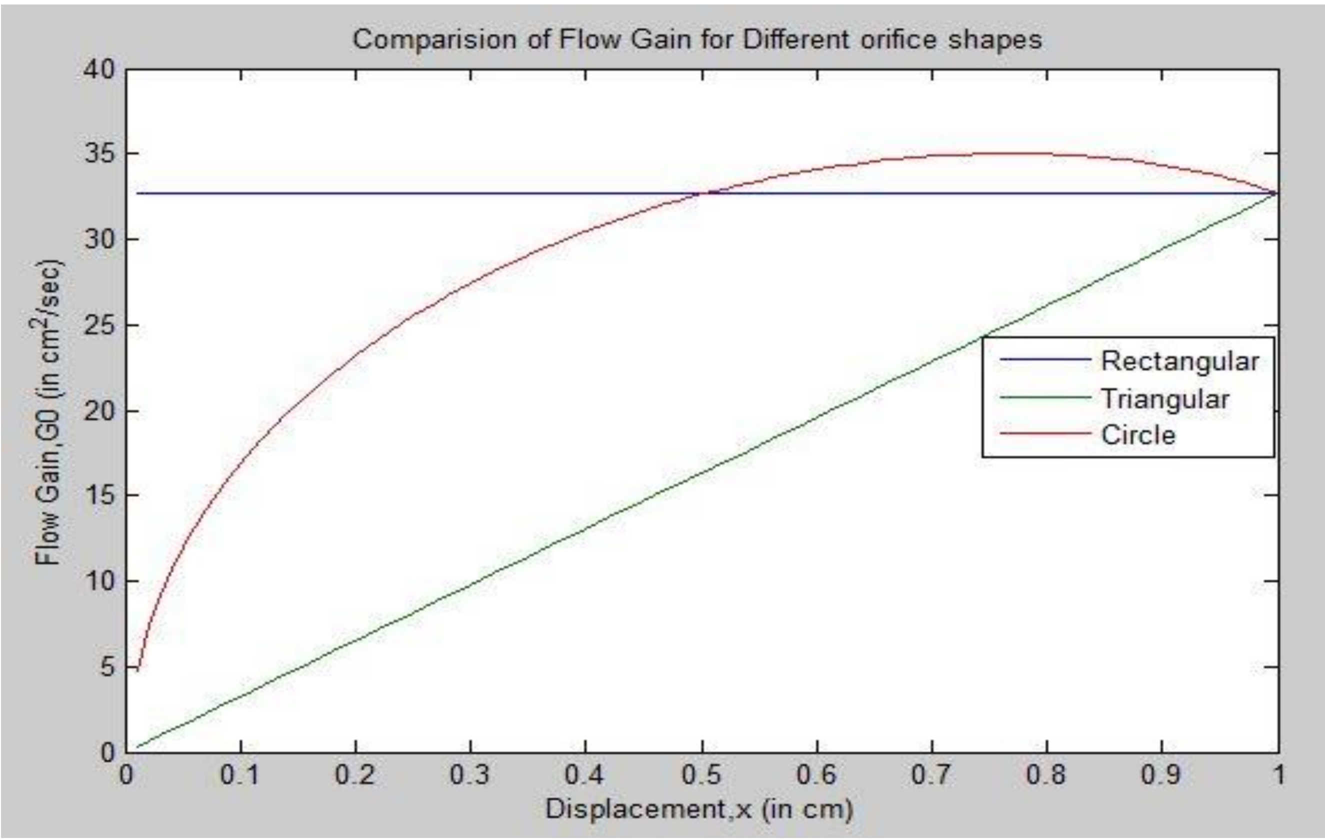


Comparison of orifice meter for different geometry:

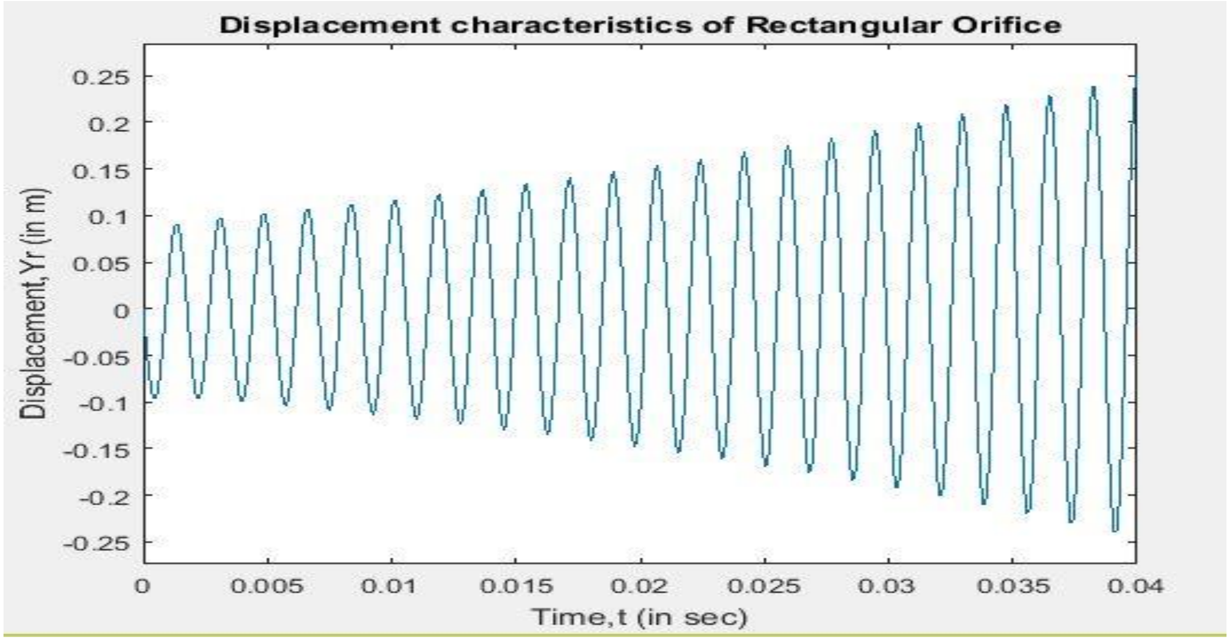


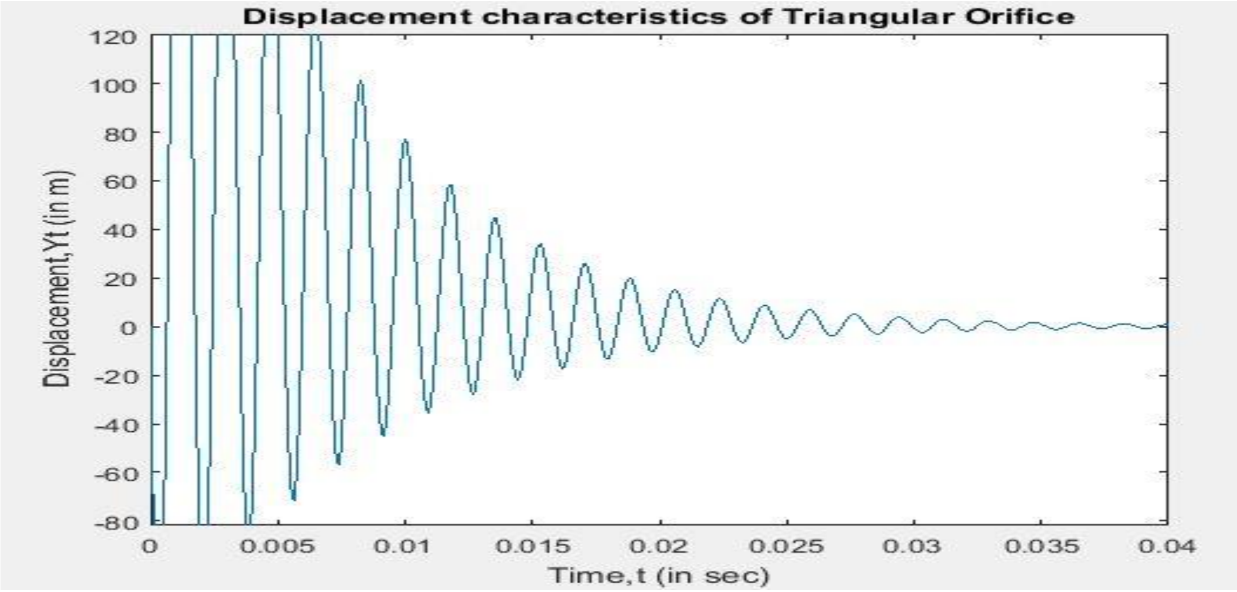
Graph for flow gain:

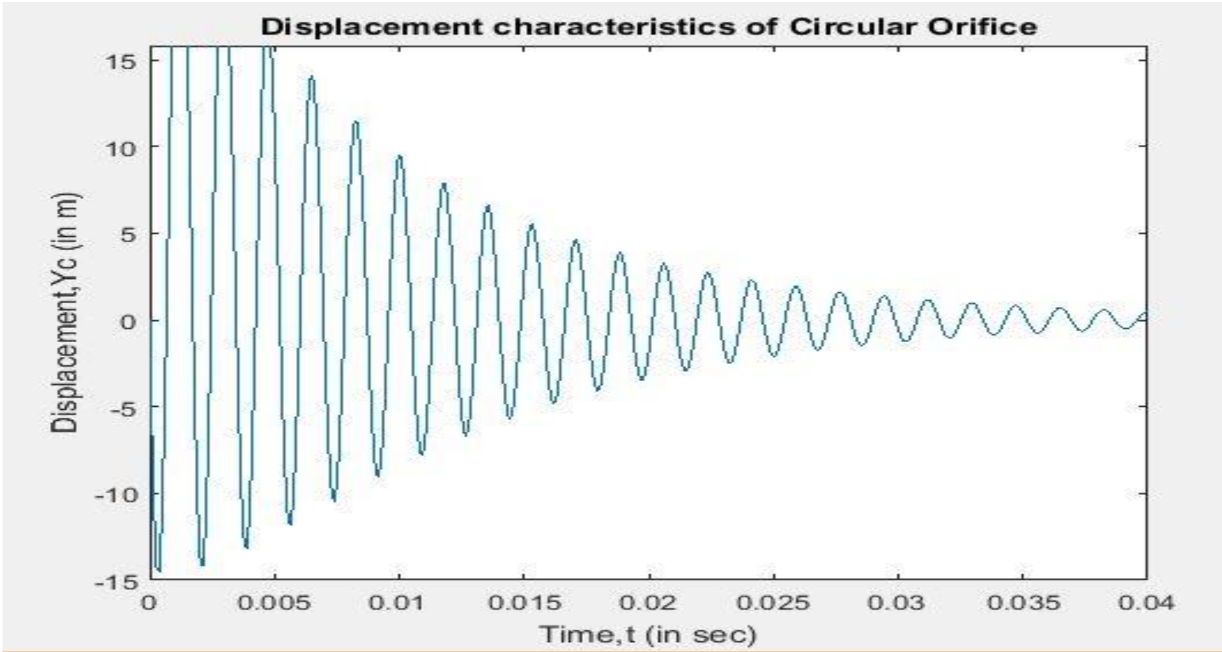
Substituting the result of equation (15) through (17) into equation (14) yields the gain of steady state flow for each orifice geometry was changed with position x_0. From figure 4 it can be seen that a triangular shape have good response for the optimal flow gain of similar size (i.e., equal width and maximum areas).


Comparision of Flow Gain for Different orifice shapes
Flow Gain,G0 (in cm2/sec)
Displacement,x (in cm)
Rectangular
Triangular
Circle
40
35
30
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Simulation results for displacement characteristics:

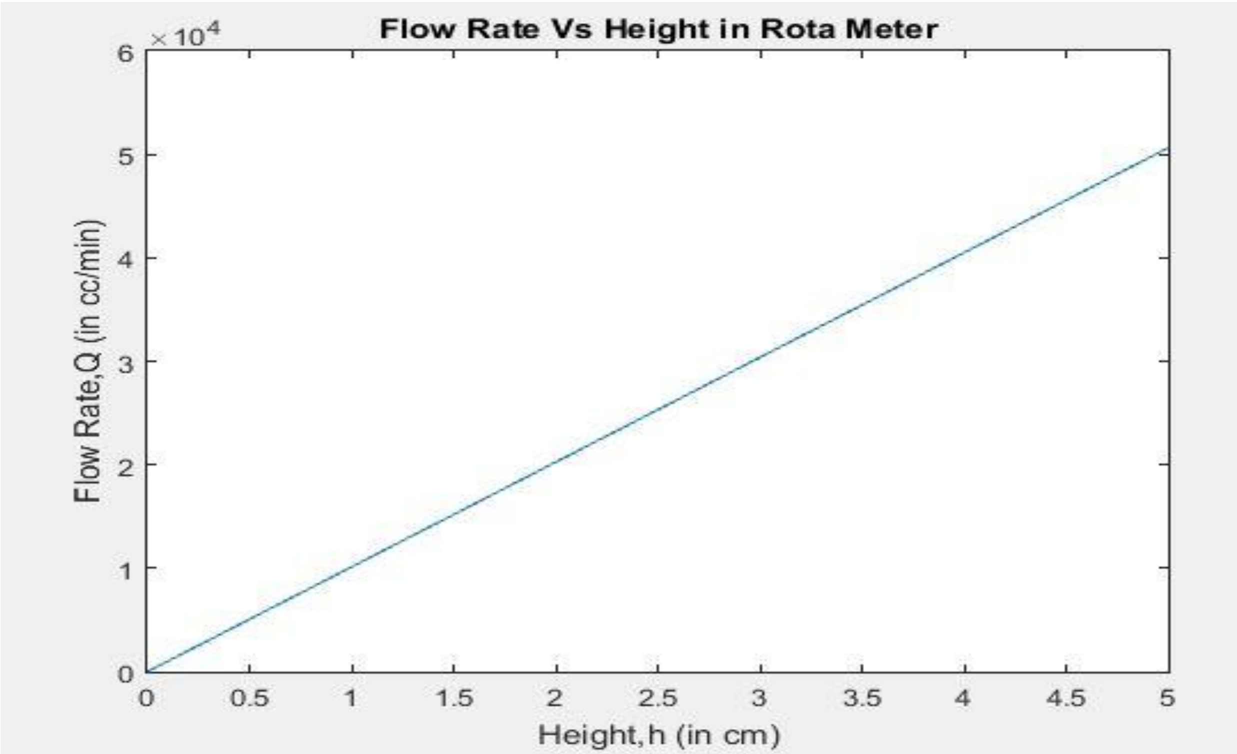




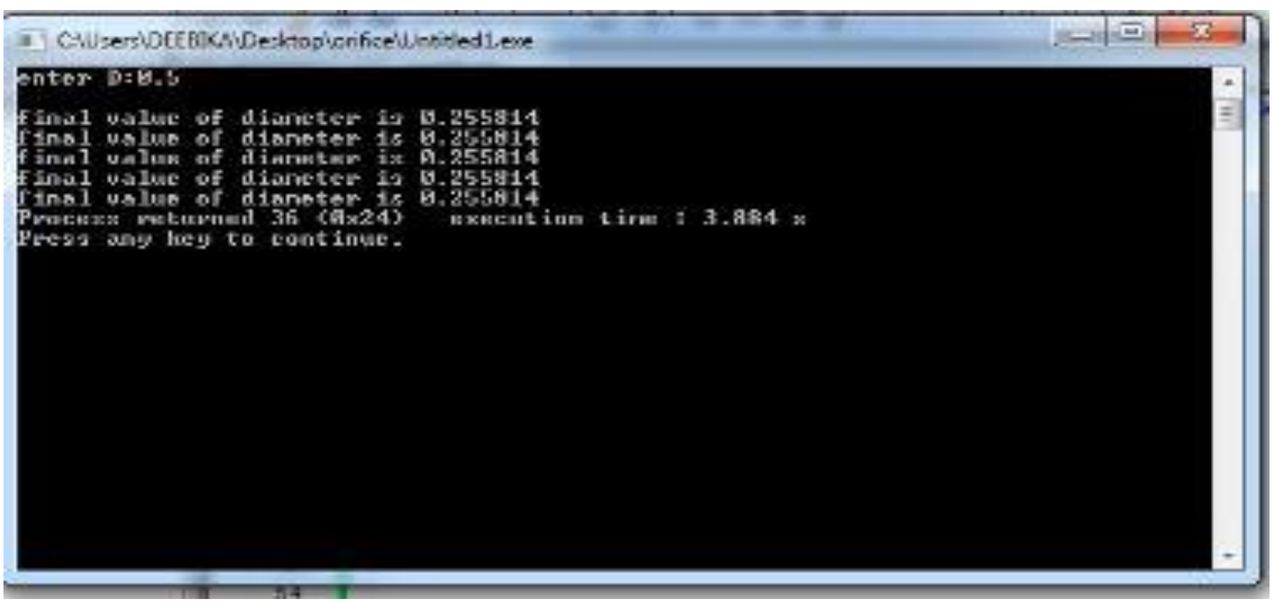

Displacement characteristics of Circular Orifice
Displacement,Yc (in m)
Time,t (in sec)
15
10
5
0
-5
-10
-15
0
0.005
0.01
0.015
0.02
0.025
0.03
0.035
0.04

5.4 STUDY OF ROTAMETER AND CALCULATION OF ORIFICE METER DIAMETER, d

4.1 For rotameter (constant pressure and variable area):



4.2.observation for the measurement of orifice meter diameter,d



CONCLUSION

Here,we have particularly showed how to measure fluid flow velocity, composition of gases in mixture using hot wire anemometer and design and analyze the fuel metering valve and calculation of orifice meter diameter,d.

In velocity measurement, the resistance of the sensor changes which is detected by the Wheatstone bridge and a feedback current is supplied to the sensor in order to keep the temperature constant and hence the temperature. In constant temperature hot wire anemometer the wire made of platinum and tungsten which is very costly. Change in resistance is only for heat transfer due to fluid not for surrounding change. We calculate the change in output for different variation, i) Effect of change in fluid. Different fluid like alcohol, water, olive oil and glycerin Output voltage change with change in fluid density and thermal conductivity. Ii) Effect of change in dimensions. Different dimension sensor change the output voltage.

In composition measurement, the most important conditions for accurate measurements is maintaining constant gas speed and correctly choosing the temperature of wire. Let's take an example, for measurement of CO_2 concentration, the temperature of the wire should not be higher than 100-120 °C because of the rapid increase in α_ϑ with temperature. In a mixture with air, this coefficient becomes almost equal to that of air and it affects the accuracy of the method.

The fuel metering valve is design and analyzed the gain, G for steady state flow which is defined by traditional linear method. The gain characteristics also depend on the geometry of the orifice and the good choice for this exists, basically, the flow area of rectangular, circular and triangular shapes are discussed. The different orifice geometry of equal size shows different results which has been shown in figure. Triangular shape is most preferred for flow passage.

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